**EVALUATION OF BIOMASS AND CARBON STOK IN AGROFORESTRY LAND USE TYPES IN NIGER STATE, NIGERIA**

**Mohammed Lawal Sanusi**

Department of Geography Technology, Federal University of Technology Minna

**Muhammed, M.**

Department of Geography Technology, Federal University of Technology Minna

**Mohammed, S.Y.**

Department of Geography Technology, Federal University of Technology Minna

**Lawal, B.A.**

Department of Soil Science and Land Management Technology, Federal University of

Technology Minna

**ABSTRACT**

*This study provides an evaluation of biomass and carbon stock in agroforestry land use types in Niger State, Nigeria. Biometric forest inventory techniques, direct biomass sampling and laboratory analysis methods were employed for data collection. Descriptive statistics was used to summarize the data while variation in carbon stock among the agroforestry land use types across study area were tested by use of analysis of variance (ANOVA). The student’s t –test was used to test for differences in carbon stock and vegetation parameters between pairs of vegetation communities. Thereafter, biomass values were converted to carbon stock equivalent. Satellite imageries of NIGERIASAT-1 of 2012 and 2020 respectively were used to estimate vegetation cover and carbon stock change over 20 years. The results showed that four major agroforestry land use types in the study area include Savanna Woodland (53.02%), Scrubland (16.5%), Grassland (15.03%) and cropland (15.45%). Results obtained also revealed that, ecologically dominant tree species in the study area in descending order are Vitalleria paradoxa, Irvingia gabonensis, Parkia biglobosa, Anogeissus leiocarpus, Pterocarpus erinaceous, Detarium microcarpum, Prosopis africana, Danellia oliveri, and Afzelia Africana; which together account for about 65.2 % of total species. Average carbon stock (Mg C/ha-1) of the agroforestry land use type was in the decreasing order; Savanna woodland (469.62±18.21), Scrubland (278.37±27.55), Grassland (153.15±12.42), and Cropland (139.35±24.31). The mean carbon stocks projections of agroforestry land use types in the study area in decreasing order are Savanna woodland (347.45 Mg C ha-1), scrubland (212.13 Mg C ha-1), grassland (124.78 Mg C ha-1), and cropland (123.94 Mg C ha-1) in the year 2050. A successful assessment and monitoring of carbon stock in savanna plant communities will largely depend on the establishment of baseline inventory data on species composition, diversity and distribution of plant communities in the study area. This study recommends the preservation of tree species such as Anogeissus leiocarpus, Parkia biglobosa, Pterocarpus erinaceous, Irvingia gabonensis and Vitellaria paradoxa for carbon offset purposes; because they are indigenous, ecologically important and show high carbon sequestration potential by virtue of their biomass stocks and the carbon stock predictor models derived provide an ideal opportunity for further work on the verification of woody biomass/carbon stock calculations, thus leading to estimations that are more meaningful in the study area.*

**Key words:** Biomass, Carbon, Stock, Savanna woodland, Agroforestry and Vegetation.

**INTRODUCTION**

Biomass is defined as the dry weight of both aboveground biomass (AGB) and belowground biomass (BGB) living mass of vegetation, such as wood, bark, branches, twigs, stumps, or roots as well as dead mass of litter associated with the soil (Raihan *et al.,* 2021). The process of absorbing atmospheric carbon by the trees is called carbon sequestration, which is one of the forest ecosystems services (Mauya and Madundo, 2021). However, forests are important in the global carbon cycle because they store large amounts of carbon in vegetation and soil. They exchange carbon with the atmosphere through photosynthesis and respiration and they are atmospheric carbon sink (net CO2 absorption of the atmosphere), they become sources of atmospheric carbon when disturbed by human or natural actions such as wildfires, logging due to poor logging procedures, brushing and burning for conversion of the forest to other uses (Ghasem *et al.,* 2021).

Furthermore, IPCC (2018) and Beck and Mahony, (2018) pinpointed the key role that land use and its management play in influencing the terrestrial ecosystem and the global climate system. In connection with this, many recent studies reported that land use-related activities, such as deforestation, enteric fermentation, and application of fertilizers, are contributors of significant proportion of total anthropogenic greenhouse gases emissions (Tubiello *et al*., 2015; Zhu *et al*., 2016). Similarly, a rapid increase in methane and nitrous oxide emission from the agriculture sector, which solely depends on land, was reported (Czubaszek *et al*., 2018; Hao-tian *et al*., 2019). Li, (2021) emphasized the significant role land is playing in the exchange of energy, aerosols, and water between its surface and the overlying atmosphere. However, this important resource is becoming increasingly vulnerable to climate change and extremes due to various drivers (Li, 2021; Zaninovich *et al*., 2016). Land degradation is often quoted as one of the most important drivers that cause unprecedented decline in land productivity and loss of other ecosystem services and biodiversity (Briassoulis, 2019; Zaninovich *et al*., 2016). As a case in point, Panagos *et al.* (2020) identified ten threats that affect soil functions, including soil erosion, nutrient imbalance, soil acidification, soil organic carbon (SOC) loss, waterlogging, salinization, soil contamination, soil compaction, soil sealing, and loss of soil biodiversity. Climate models projected not only an increase in mean temperature and a large variability of rainfall, but also forecasted more frequent heat waves and extreme droughts in the future (IPCC, 2018; Kopittke *et al*., 2019). The mean temperature during the growing season at the end of the 21st century will be higher than the extreme seasonal temperature observed for the period 1900 to 2006. In the future, these changes are likely to affect the suitability of a given parcel of land for crop production or any other use. Selecting land uses that are possible under these changed conditions might become imperative.

**Literature Review**

**Carbon stock**

The prominent factor inducing climate change is the increase in the concentration of greenhouse gases (GHGs) in the atmosphere. The ever increasing concentrations of carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), and other GHGs have distorted the balance between the incoming and the outgoing solar radiation emitted by the Sun and Earth, respectively (Lal, 2010; Ciais *et al*., 2013). According to IEA (2015), carbon dioxide has increased from its pre-industrial 280 ppm to 397 ppm (IEA, 2015). On the other hand, Dlugokencky and Tans (2018) reported a 128 ppm increase in concentration of carbon dioxide in the atmosphere between 1750 (beginning of pre-industrial period) and 2017. The two most common factors distorting the carbon cycle are land use change and combustion of fossil fuel (Ciais *et al*., 2013). Practically, about 75% of the global CO2 emissions come from the combustion of fossil fuels in transportation, building heating and cooling, and manufacture of cement and other goods. In Ethiopia, the emission from fossil fuel generated 2.3 million tonnes of CO2 in 1990 and the figure increased to 8.5 million tonnes of CO2 in 2013 (IEA, 2015).

**Carbon sequestration in agriculture**

Carbon sequestration refers to the removal of carbon (C) from the atmosphere and deposition or storage in a reservoir such as oceans, vegetation or soil (Smith, 2019). Carbon sequestration in terrestrial ecosystems such as agroforestry systems and practices involves primarily the uptake of atmospheric CO2 through photosynthesis and transfer of the fixed carbon into biomass, detritus, and soil pools for storage (Nair, 2016). Agricultural production has profound impact on global carbon and estimated to have about 24% contribution to global greenhouse gasses emission (Zomer *et al.*, 2017). The global soil carbon (C) pool is about 3.2 times the size of the atmospheric pool and four times that of the biotic pool (Lal, 2010). Cropland soil has the potential to sequester C and is thus important as a CO2 sink (Zomer *et al.*, 2017). Globally, cropland stores more than 140 x 109 t C in the top 30 cm of soil, which is about 10% of the total global SOC pool (Paustian *et al*., 2016). Croplands can be one of the best options to enhance carbon sequestration in the soil since there are different options to improve their potential through better management. Past estimates indicated that 50 to 70% of soil carbon stock in cultivated soils has been lost (Lal, 2010). Hence, croplands have huge potential to sequester carbon until it reaches saturation point (Sommer and Bossio, 2014).

**Biomass**

Tree-based land-use systems such as native forest, forest plantations and agroforestry systems sequester CO2 through the carbon stored in their biomass (Nair, 2016). The most significant increases in C storage can be achieved by moving from lower-biomass land-use systems (e.g. grasslands, agricultural fallows and permanent shrub lands) to tree-based systems. Forest ecosystems store more than 80% of all terrestrial aboveground C and more than 70% of all soil organic C (Paustian *et al*., 2016). Vegetation is a major component of the global C cycle and is estimated to store at least 350 C (Dlugokencky and Tans (2018). It is subject to increase or decrease as a result of factors such as harvest, re-growth, conversion to other land uses, with resulting changes in C fluxes to the atmosphere. There is an ever-increasing need to improve the accuracy of estimates of C storage in biomass so that its role in the global C cycle can be characterised and understood.

**Agroforestry**

Agroforestry is a collective name for a land-use system and technology whereby woody perennials are deliberately used on the same land management unit as agricultural crops and/or animals in some form of spatial arrangement or temporal sequence (Kopittke *et al*., 2019). In an agroforestry system, there are both ecological and economic interactions between the various components. Agroforestry practices also play an important role in conserving biodiversity. They can also provide substantial co-benefits in enhancing resilience (adaptation) to climate change and rainfall variability by improving soil fertility, thereby increasing productivity and diversifying farm income (Haile *et al.,* 2017). Agroforestry is the third-largest C sink after primary forests, followed by long-term fallows in Africa. In agroforestry, trees store about 3 to 4 fold higher carbon stocks than crop and pasture lands without trees, with C stocks ranging from 29–228 Mg ha− 1 (Nair *et al*., 2011). On a global scale, the total land area under different types of agroforestry systems is about 1.6 billion hectares, with a carbon sequestration potential of C over the next 50 years.

**Effects of Agroforestry on Biomass and Carbon Stock**

Anthropogenic activities like excessive changes in land use patterns, clearing of forests, and burning of fossil fuels are liable for the continuous emission of atmospheric carbon dioxide, prompting climate change across the globe (Kopittke *et al*., 2019). CO2 is considered a major greenhouse gas and the largest single contributor (>70%) to global warming due to its rapid increase in the air since industrialization. The annual accumulation rate of CO2 in the atmosphere is about 3.5 ppm, thus creating real threats to the global environment. If this addition continues till the next century, the earth’s temperature will rise possibly 20C, resulting in 20-30% destruction of ecosystems worldwide (Haile *et al.,* 2017). Agroforestry is an effective management strategy for enhancing the ecosystem services generated by agricultural lands. Agroforestry systems are considered a potential source in alleviating climate change across the globe as trees planted on farmlands greatly enhance the capability of those systems to capture and store carbon.

**METHODOLOGY**

Reconnaissance survey was used to collect data for the study in the study area. Each forest will be divided into four parts where one line run through the centre from east to west and the other running from south to north. In order to locate quadrant for based agroforestry, the four transect lines will be extended up to 2km. On each line, EW and S-N a series of quadrats was laid. Hence, 12 quadrats in each transect will be established with 48 quadrats to be used for biomass evaluation. Similarly, in each patch natural forests the total of 48 quadrats (16 quadrats for each) was used for both vegetation and carbon stock evaluation. AGB for the tree species strata was estimated from measured DBH and tree height using a generalized tree biomass regression equation for the specific precipitation zone (Makinde *et al.,* 2017):

$y= e^{(- 3.1141+0.9719In(DBH×H)}, $ (1)
where y is the above ground biomass (AGB) in kg; DBH, diameter at breast height in cm;

H is the height of tree (m) and this will converted to tonha1 by multiplying by 0.001with r2 = 0.97.

The AGB for the entire stand was multiplied by the land cover area estimation.

$y\_{landcover}=\sum\_{}^{}e^{ (-3.1141+0.9719In(DBH\_{landcover}×H\_{landcover})}$(2)

Total AGB of each land cover $y\_{TOTAL}=y\_{landcover × }$Area of land cover

Below ground biomass (BGB) was estimated from AGB. According to Makinde *et al.* (2017) a non-destructive approach depends on belowground biomass values for vegetation as 20% of the aboveground biomass. Below ground biomass = 20% × above ground biomass

 i.e. $BGB=20\% ×AGB$ (3)

The plant communities under agroforestry land use types include Savanna Woodland (SW), Scrubland (SL), Grassland (GL) and Cropland (CL). The plant community parameters measured include Species per Plot (SP), Tree Crown Cover (TCC), Shrub Cover (SC), Grass Cover (GC), Tree Height (TH), Diameter at Breast Height (DBH), Basal Area (BA), Carbon stock (CS) and Biomass. For the determination of soil organic carbon, one sample was taken from each of the 1m2 subplot quadrats at two depths (0-15cm and 15-30cm), with the aid of soil core sampler of 188.5 cm3 volume (2 cm radius x 15 cm length cylinder). The four samples collected per plot were mixed by depth category to produce two composite samples. For the determination of bulk density, two separate coring rings of volume 98.2 cm3 (2.5 cm radius x 5 cm length cylinder) were used to collect undisturbed soil samples at two depths (0 -15 cm and 16 – 30 cm). Within each of the four 1m2 quadrats, sample was first taken for savanna woodland and scrubland, then for litter and lastly for soil. Carbon stock data was collected from five major carbon pools viz above ground trees, Undergrowth, Root carbon stock, Litter, and Dead wood. Measurement of carbon pools was achieved by their respective techniques such as above ground tree pool by biomass sampling/allometry equation; Below ground tree pool by allometry model; Undergrowth pool by clip plot method; Dead wood pool by line transect method; Litter pool by clip plot method; and Soil pool by soil core sampling/laboratory analysis method. Samples collected were weighed at sampling points with the aid of weighing scales. Thereafter, subsamples of shrub, grasses, dead wood, and litter collected from the field and transported to the laboratory for moisture content analysis at constant-temperature. Soil samples for organic carbon and bulk density was also subjected to laboratory analysis. The summation of carbon stock in the respective pools give the total carbon stock per sample plot. Descriptive statistics used to summarize the data include average mean, standard deviation, standard error, percentage, frequency and coefficient of variation. The variation in carbon stock densities among the agroforestry land use types across study area were tested by use of analysis of variance (ANOVA). The student’s *t* –test was used to test for differences in carbon stock and vegetation parameters between pairs of vegetation communities and specifically between the savanna woodland and scrubland. Statistical tests were performed at 0.05, 0.01, and 0.001 significant levels.

**RESULT AND DISCUSSION**

**Agroforest land use types and plant communities**

This section describes the agroforestry land types commonly used by the farmers in the study area, which includes savanna woodland, scrubland, grassland and cropland respectively. Table 4.1 indicates that Savanna woodland constitutes the largest 53.02% of the agroforestry land use in the study area. The vegetation cover is eventually decreasing as a result of indiscriminate exploitation of forest resources for human use. On the other hand, while the area coverage of scrubland, is 16.5% of the agroforestry land in the study area. However, decrease in the savanna woodland and scrubland increase the available grassland (15.03%) and cropland (15.45%). Exceptionally, Grassland coverage experienced an increase between 2012 and 2020.

**Table 1: Agroforestry land types area coverage over the study area**

|  |  |  |  |
| --- | --- | --- | --- |
| **Agroforestry land use types** | **Area of land (ha)** | **Frequency** | **percentage** |
| Savanna woodland  | 7930.30 | 9 | 53.02 |
| Scrub land  | 2467.40 | 15 | 16.50 |
| Grassland  | 2247.81 | 8 | 15.03 |
| Crop land  | 2311.78 | 29 | 15.45 |
| **Total**  | **14957.29** | **60** | **100** |

Source: Authors field work, 2023.

**Composition of Woody Species over the study area**

A total of 1,505 individual woody stands representing 36 species, 18 genera and 18 families were identified and enumerated in all agroforestry plant communities found in the study area. Table 4.2 shows that the dominant tree species in the study area in the decreasing order are *Vitalleria paradoxa,* (13.8%) *Irvingia gabonensis* (9.2%), *Parkia biglobosa* (8.0%), *Annona senegalensis* (7.7%), *Pterocarpus erinaceous* (7.4%), *Detarium microcarpum* (5.7%), *Prosopis africana* (5.7%), *Danellia oliveri* (4.2%), and *Afzelia Africana* (3.5%); which together account for about 65.2% of species dominance in the study area. Furthermore, the most dominant families are *Fabaceae, Malvaceae, Moraceae,* and *Combrataceae*. The observed dominance of specific species and species families over the study area can be attributed to the effect of species ecological amplitude (environmental tolerance) whereby plant communities are basically a consequence of rigorous habitat selection that denies opportunity to all but a relatively few of the great variety of species (Jibrin *et al.,* 2018). Thus, plant species tend to be grouped in different combinations forming more or less definite communities. Each community is characterized by certain species, which are inconspicuous or unrepresented in other communities.

**Table 2: Composition of woody species over the study area**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S/N** | **Tree species** | **Genus** | **Family** | **Percentage composition** |
| 1 | *Vitellaria paradoxa*  | *Vitellaria* | *Sapotaceae* | 13.8 |
| 2 | *Irvingia gabonensis*  | *Irvingia* | *Irvingiacea* | 9.2 |
| 3 | *Parkia biglobosa*  | *Parkia* | *Mimosaceae* | 8.0 |
| 4 | *Annona senegalensis* | *Annona* | *Annonaceae* | 7.7 |
| 5 | *Pterocarpus erinaceous*  | *Pterocarpus* | *Fabaceae* | 7.4 |
| 6 | *Detarium microcarpum*  | *Detarium* | *Caesalpiniaceae* | 5.7 |
| 7 | *Prosopis africana* | *Prosopsis* | *Fabaceae* | 5.7 |
| 8 | *Danellia oliveri*  | *Danellia* | *Caesalpiniaceae* | 4.2 |
| 9 | *Afzelia africana*  | *Afzelia* | *Fabaceae* | 3.5 |
| 10 | *Khaya senegalensis*  | *Khaya* | *Meliaceae* | 3.4 |
| 11 | *Adansonia digitata*  | *Adansonia* | *Malvaceae* | 1 |
| 12 | *Ceiba pentandra*  | *Ceiba* | *Malvaceae* | 0.9 |
| 13 | *Tamarindus indica*  | *Tamarindus* | *Fabaceae* | 0.9 |
| 14 | *Elaeis guineensis*  | *Elaeis* | *Fabaceae* | 0.8 |
| 15 | *Mangifera indica*  | *Mangifera* | *Anacardiaceae* | 0.6 |
| 16 | *Acacia senegal*  | *Acacia* | *Fabaceae* | 0.2 |
| 17 | *Cocos nucifera*  | *Cocos* | *Malvaceae* | 0.1 |
| 18 | *Anacardium occidentale*  | *Anacardium* | *Anarcardiaceae* | 0.1 |

Source: Field survey, 2023.

**The carbon stock of land use types**

**Aboveground carbon stock**

Due to absence of trees on sample plots under cropland and grasslands, biomass measurement was only made on savanna woodland and scrubland agroforestry land uses. The savanna woodland was found to have significantly higher biomass carbon stock compared with the scrubland’s agroforestry land use. In the savanna woodland, 83.3% share of the biomass carbon stock was attributed to the aboveground biomass (Table 4.8). Particularly trees with dbh ≥ 30 cm had contributed the largest carbon (Table 4.7). In the scrubland agroforestry land use, small number of shade trees with small diameter were encountered and measured. Accordingly, the share of aboveground biomass (savanna woodland and scrubland) was 93.59% of the biomass carbon stock of the agro-forestry land use. However, aboveground carbon was measured under the savanna woodland and scrubland agroforestry land use types only. The grass and croplands did not have any measurable aboveground biomass and, hence, aboveground carbon stock was not measured. The aboveground biomass carbon stock in the savanna woodland was higher than that in the scrubland agroforestry due to the presence of many large trees and other vegetation cover. This indicates that presence of trees in a given environment ensures storage of biomass carbon in addition to its sequestration through the process of photosynthesis. This helps greatly in mitigating climate change. The large aboveground carbon stock density in the savanna woodland could be associated with the presence of higher density of trees with larger diameter at breast height (dbh) (Dumitras *et al*., 2020).

**Belowground biomass**

Irrespective of altitudinal gradients, maximum mean belowground biomass (22.23 t ha-1) is recorded in the savanna woodland (Table 4.8), whereas minimum belowground biomass (3.45 t ha-1) is recorded in the scrubland agroforestry land use. However, aboveground carbon was measured under the savanna woodland and scrubland agroforestry land use types only. The grassland and croplands did not have any measurable belowground biomass and, hence, belowground carbon stock was not measured. The belowground biomass carbon stock in the savanna woodland was higher than that in the scrubland agroforestry due to the presence of many large presence of litters’ composition, root of the trees and other vegetation cover.

**Root carbon stock**

The root carbon stock estimated from the aboveground biomass (20%) was 23.29±3.56 and 3.43±0.34 ha-1 for savanna woodland and scrubland agroforestry, respectively. Roots are important in terms of carbon balance as they are transferring large amounts of carbon into the soil. In this regard, savanna are central in storing carbon below the plough layer, which is more stable. In an environment with vegetation cover, roots are important sources of soil organic carbon (Raihan *et al*., 2021). The lower carbon stock in this study could be the result of lower aboveground biomass since the root carbon stock was estimated from the aboveground biomass. Comparatively, however, the root carbon stock in the savanna woodland was higher than that in the scrubland agroforestry land use, implying that forests could be better in storing carbon in their deep root system. This is in line with Iván *et al*. (2019) who indicated that trees with deep root systems could store substantial amount of carbon in their root biomass, though this is expected to decrease with soil depth. Abdullahi *et al*. (2014) argues that this contribution is strongly influenced by other site- and land use change-specific variables. Furthermore, the status of the forest and its species composition along with climatic and edaphic factors could create differences in root carbon stock among forests. The aboveground biomass is subject to different removal processes, the root can be seen as a very good venue where carbon could be sequestered. Therefore, accurate assessment of the root carbon stock using direct instead of the indirect methods should be followed, to get better estimates of the root carbon stock.

**Litter carbon stock**

The litter carbon stock in the savanna woodland and scrubland agroforestry was 0.69±0.08 and 0.36±0.04 t ha-1, respectively. There was no litter on croplands, for crop residue is used for livestock feed, fuel and construction in the study area. Similarly, there was no litter in the grassland since there was no grass leftover on grass lands due to heavy grazing and cut and carry system practiced in the study area. Litter is another important source of organic carbon, particularly in ecosystems covered with natural vegetation. As pointed out by Tessema and Kibebew, (2019), supply of carbon into the soil depends on litter decomposition rate, which in turn is influenced by litter quality and plant species diversity. The litter carbon stock recorded under the savanna woodland and scrubland agroforestry land use types was higher as compared to that recorded in grassland and cropland areas. The lower litter carbon in the study area could be associated with the presence of few and less divers trees in the grassland and cropland agroforestry land use in the study area. As indicated by Iván *et al*. (2019), litter plays a very important role in the carbon bio-geological cycle as the interface between carbon in vegetation and in soil. Hence, litter management is important to guarantee continuous flow of organic matter in the system. In an environment with vegetation cover, roots are important sources of soil organic carbon (Raihan *et al*., 2021). The lower carbon stock in this study could be the result of lower aboveground biomass since the root carbon stock was estimated from the aboveground biomass. Comparatively, however, the root carbon stock in the savanna woodland was higher than that in the scrubland agroforestry land use, implying that forests could be better in storing carbon in their deep root system. This is in line with Iván *et al*. (2019) who indicated that trees with deep root systems could store substantial amount of carbon in their root biomass, though this is expected to decrease with soil depth. Abdullahi *et al*. (2014) argues that this contribution is strongly influenced by other site- and land use change-specific variables. Furthermore, the status of the forest and its species composition along with climatic and edaphic factors could create differences in root carbon stock among forests. The aboveground biomass is subject to different removal processes, the root can be seen as a very good venue where carbon could be sequestered. Therefore, accurate assessment of the root carbon stock using direct instead of the indirect methods should be followed, to get better estimates of the root carbon stock.

**Dead wood carbon stock**

Dead wood was not observed in the savanna forest area during reconnaissance survey and also not encountered in the sample plots. Hence, no carbon stock measurement was made for dead wood. Similarly, debris’ carbon stock was not considered due to the fact that the croplands investigated did not have debris as a carbon pool and the savanna forest debris is often harvested for fuel and structural timber. People living around the savanna forest are highly dependent on the forest for their energy requirement and frequently collect dead wood from the forest. Although this is an important component of carbon pool in a forest ecosystem, the continuous disturbance of the forest has resulted in complete utilization of any of the trees that are dead.

**Table 3: Carbon stock of different agroforestry land use (t ha-1)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Agroforestry land use types** | **Carbon stock in different carbon pools** |  |  |  |  |
|  | **AGC** | **BGC** | **LC** | **SOC** | **Total carbon** |
| Savanna woodland  | 116.56±18.71  | 22.23±3.56  | 0.69±0.08  | 319.39±21.02  | 469.62±18.21c  |
| Scrubland  | 16.25±1.9  | 3.45±0.36  | 0.37±0.04  | 269.49 ±25.54  | 278.37±27.55b  |
| Grassland  |  |  |  | 153.15±12.42  | 153.15±12.42a  |
| Cropland  |  |  |  | 139.85±24.01  | 139.35±24.31a  |

Source: Field survey, 2023.

For each parameter, different letters in a column indicate significant differences (p<0.5) with respect to land uses.

AGC= Aboveground carbon, BGC= Belowground carbon, LC = Litter carbon, SOC= Soil organic carbon.

**Simulate the biomass carbon stock per Agroforest land use type by year 2050**

Carbon stock projections in the various agroforestry land use types is presented in Table 4.9. The mean carbon stocks of plant communities in decreasing order are Savanna woodland (347.45 Mg C ha-1), scrubland (212.13 Mg C ha-1), grassland (124.78 Mg C ha-1), and cropland (123.94 Mg C ha-1). Under similar environmental conditions, different plant species have different structures and mortality rates. Variation in the structure and composition of plant communities and quantitative properties of their diversity constitute variables that determine variation in carbon stock over a landscape. Improvements have been considered for all agroforestry land use types, projections to base-year’s of 2050 to avoid infeasible assumptions. Nevertheless, at the end of the analysed period, 26% change in the savanna woodland agroforestry land use show highest percentage change in the biomass carbon stock in the agroforestry land use type from other lands. Only the grassland and cropland agroforestry land use types were able to provide minimum C stock reductions. The savanna woodland was due to the forest exploitation of the rural settlers around the land types that causes the increase for above ground and below ground biomass carbon stock reduction by the year 2050, while for the scrubland agroforestry land use (212.13 Mg C ha-1) provided large amounts of carbon stocks reduction per unit area in both biomass pools by the year 2050 by 23.79%. When analysing the reforestation scenario, results indicate that carbon sequestration and storage potential from reforestation either in living biomass or in wood products could provide significant GHG abatement potential, especially in the savanna woodland (347.45 Mg C ha-1) and scrubland (212.13 Mg C ha-1). The cropland land use lost (11.05%) of carbon stock, mainly from an agricultural sector that is still in expansion and does not liberate agricultural land for the first 20 years, therefore deforestation still occurs. In addition, when cleared land is available (mostly after 2035), the region has the lowest carbon stock succession rates from reforestation due to a lower carbon content forest by unit area such as the scrubland.

**Table 4: Mean of carbon stock estimates by the year 2050**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Agroforestry land use types** |  |  |  | **Carbon stock Mg C ha-1** |  |  |  |
|  | **2023** | **2030** | **2035** | **2040** | **2045** | **2050** | **%∆C** |
| Savanna woodland  | 469.62 | 363.83 | 348.22 | 343.27 | 334.34 | 347.45 | 26.01 |
| Scrubland  | 278.37 | 256.38 | 227.85 | 219.35 | 215.36 | 212.13 | 23.79 |
| Grassland  | 153.15 | 146.04 | 138.34 | 137.16 | 125.47 | 124.78 | 18.52 |
| Cropland  | 139.35 | 135.29 | 137.98 | 133.71 | 125.70 | 123.94 | 11.05 |
| Total  | 1040.49 | 901.54 | 852.39 | 833.49 | 800.98 | 808.3 | 22.31 |

Source: Authors Field work, 2023

**CONCLUSIONS**

This study provides a scientific contribution for accurate estimations of biomass and carbon stock in agroforestry under major land use in Niger state, Nigeria. These estimates are useful benchmark against which future estimates can be compared and sets a baseline for calculating changes in carbon stocks over time. A successful assessment and monitoring of carbon stock in savanna plant communities will largely depend on the establishment of baseline inventory data on species composition, diversity and distribution of plant communities in the study area.The description of species composition, structure and diversity of different plant communities confirms the principle of habitat heterogeneity (patchiness) which increases tree diversity in savanna woodland and scrubland. The ecologically dominant tree species (based on specie importance value S.I.V.) in the study area in descending order were *Vitalleria paradoxa, Irvingia gabonensis, Parkia biglobosa*, *Anogeissus leiocarpus*, *Pterocarpus erinaceous*, *Detarium microcarpum*, *Prosopis africana*, *Danellia oliveri*, and *Afzelia Africana*; which together account for about 65.2% of total species dominance. The dominance of specific species also confirms the principle of ecological amplitude. The results were in sequence with previous studies which together show consistent ecological patterns. Species composition and structure followed trend in the eco-region with dominance of typical Guinea savanna tree species. Tree species that contribute most to the above ground biomass stock in the study area were *Anogeissus leiocarpus*, (401.98kg) *Parkia biglobosa,* (352.9kg) *Pterocarpus erinaceous,* (290.63kg) *Irvingia gabonensis* (258.83kg) and *Vitellaria paradoxa* (204.3kg). Finding in this study implies that *Anogeissus leiocarpus* is the tree species with highest potential to store carbon in the study area. The mean carbon stocks of plant communities in decreasing order were Savanna woodland (469.62 Mg ha-1), Scrubland (278.37 Mg ha-1), Grassland (153.13 Mg ha-1) and cropland (139.35 Mg ha-1). However, Carbon stock projections in the various agroforestry land use types shows the mean carbon stocks of plant communities in decreasing order are Savanna woodland (347.45 Mg C ha-1), scrubland (212.13 Mg C ha-1), grassland (124.78 Mg C ha-1), and cropland (123.94 Mg C ha-1) respectively.

**Recommendations**

1. This study recommends the preservation of tree species such as *Anogeissus leiocarpus, Parkia biglobosa, Pterocarpus erinaceous, Irvingia gabonensis and Vitellaria paradoxa* for carbon offset purposes; because they are indeginous, ecologically important and show high carbon sequestration potential by virtue of their biomass stocks.
2. Interventions that improve and maintain the carbon stock under the different land use/cover types should be identified, tested, and implemented in economically feasible and environmentally sound ways.
3. The carbon stock predictor models derived here provide an ideal opportunity for further work on the verification of woody biomass/carbon stock calculations, thus leading to estimations that are more meaningful.
4. This study recommends strengthening of and enforcement of forestry laws to ensure sustainability of this ecosystem. This will go a long way in the realization of full carbon sequestration potential of the study area.
5. Forest management activities and practices in the study area should focus on fire management and human land-use practices such as restriction on logging, bush burning, and adequate supply of kerosene, electricity and gas as alternative household cooking fuels. This would enhance carbon sink and reduce carbon emission of the plant communities in the study area.
6. Further research should be implemented to demonstrate the feasibility of large area measurement schemes in the study area. In addition, there is the need for temporal periodic studies to understand carbon stuck dynamics in the study area. This will contribute towards clear understanding of the existing carbon dynamics in the area.

**REFERENCES**

Abdullahi, J., Sule, M.Z., Aishatu, A. Sakoma, J. Kaura, A., & Bitrus, B., (2014). Carbon Sequestration Potential of Kpashimi Forest Reserve, Niger State, Nigeria. *International Journal of Geography and Geology.* 3(12)*, Pp. 145-158.*

Briassoulis, H. (2019). Combating land degradation and desertification: The land-use planning quandary. *Land*, *8*(2), 27.

Beck, S., & Mahony, M. (2018). The IPCC and the new map of science and politics. *Wiley Interdisciplinary Reviews: Climate Change*, *9*(6), e547.

Czubaszek, Robert, and Agnieszka Wysocka-Czubaszek.(2018). "Emissions of carbon dioxide and methane from fields fertilized with digestate from an agricultural biogas plant." *International Agrophysics* 32.1

Ciais, P.C., Sabine, G.B., Bopp, L., Brovkin, V., Piao, S. & Thornton, P. (2013). Carbon and Other Biogeochemical Cycles. In: Climate Change 2013b: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Dumitras, M., Kucsicsa, G. Dumitrică, C. Popovici, E.A. Vrînceanu, A. Mitrică, B. & Mocanu, I.S., (2020). Estimation of Future Changes in Aboveground Forest Carbon Stock in Romania. A Prediction Based on Forest-Cover Pattern Scenario. *Forests*, *11*, 914.

Dlugokencky, E. & Tans, P. (2018). Trends in atmospheric carbon dioxide, National Oceanic & Atmospheric Administration, Earth System Research Laboratory (NOAA/ESRL), available at: http: //www.esrl.noaa.gov/gmd/ccgg/trends/global.html

Ghasem, N., Valappil, R. S. K., & Al-Marzouqi, M. (2021). Current and future trends in polymer membrane-based gas separation technology: A comprehensive review. *Journal of Industrial and Engineering Chemistry*, *98*, 103-129.

Haile, G., Lemenih, M., Senbeta, F. and Itanna, F. (2017). Plant diversity and determinant factors across smallholder agricultural management units in Central Ethiopia Agroforestry System, 91, 677–695.

Hao-tian, Z.H.A.O., Lin-qing, W.A.N.G., Yong, Z.H.E.N.G., Tian-zi, X.I.E., Yu- xuan, J.I.A.N.G., Gu-tang, G.O.N.G., & Jun-hua, C.H.E.N. (2019). Dynamic Change Analysis of Vegetation Coverage in Qingshen County Based on Landsat. , *40*(5), 23-28.

Iván, G.K., Sara, G., Francisca, J. & Adam, H., (2019). Carbon Sequestration Potential from Large-Scale Reforestation and Sugarcane Expansion on Abandoned Agricultural Lands in Brazil. *International Journal of Geography and Geology.* 2: pp 9-25.

IPCC (2018). Climate Change and Land: An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems, Summary for Policymakers

International Energy Agency (IEA) (2015). World Outlook Energy 2015. http://www.iea.org/t&c. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome.

Jibrin, A., Jaiyeoba, I.A., & Oladipo, E.O., (2018). Analysis of Carbon Stock Density in Protected and Non- Protected areas of Guinea Savanna in Niger State, Nigeria. *Bayero Journal of Pure and Applied Sciences*, 11(2): 149 – 155

Kopittke, Peter M., Neal W. Menzies, Peng Wang, Brigid A. McKenna, and Enzo Lombi (2019). "Soil and the intensification of agriculture for global food security." *Environment international* 132: 105078.

Li, K. (2021). Climate change and aerosol sciences. *Journal of Earth Sciences and Geotechnical Engineering*, *11*(1), 1-13.

Lal, R. (2010). Managing soils and ecosystems for mitigating anthropogenic carbon emissions and advancing global food security. *BioScience,* 60, 708–721.

Makinde, E. O., Womiloju, A. A., & Ogundeko, M. O. (2017). The geospatial modelling of carbon sequestration in Oluwa Forest, Ondo State, Nigeria. *European Journal of Remote Sensing*, *50*(1), 397-413.

Mauya, E. W., & Madundo, S. (2021). Aboveground biomass and carbon stock of usambara tropical rainforests in Tanzania. *Tanzania Journal of Forestry and Nature Conservation*, *90*(2), 63-82.

Nair, R. K., Perks, M. P., Weatherall, A., Baggs, E. M., & Mencuccini, M. (2016). Does canopy nitrogen uptake enhance carbon sequestration by trees?. *Global change biology*, *22*(2), 875-888.

Panagos, Panos, Pasquale Borrelli, and David Robinson, (2020). "FAO calls for actions to reduce global soil erosion." *Mitigation and Adaptation Strategies for Global Change* 25: 789-790.

Paustian, K., Lehmann, J., Ogle, S., Reay, D., Robertson, G.P. & Smith, P. (2016). Climate-smart soils. *Nature,* 532, 49–57.

Raihan, A., Begum, R. A., & Said, M. N. M. (2021). A meta-analysis of the economic value of forest carbon stock. *Geografia–Malaysian Journal of Society and Space*, *17*(4), 321-338.

Smith, P., Adams, J., Beerling, D. J., Beringer, T., Calvin, K. V., Fuss, S., ... & Keesstra, S. (2019). Land-management options for greenhouse gas removal and their impacts on ecosystem services and the sustainable development goals. *Annual Review of Environment and Resources*, *44*, 255-286.

Sommer, R., & Bossio, D. (2014). Dynamics and climate change mitigation potential of soil organic carbon sequestration. *Journal of environmental management*, *144*, 83-87.

Tubiello, F.N., (2015). "Estimating greenhouse gas emissions in agriculture: a manual to address data requirements for developing countries." *Estimating greenhouse gas emissions in agriculture: a manual to address data requirements for developing countries.*

Tessema, T., & Kibebew, K., (2019). Carbon stock under major land use/land cover types of Hades sub‑watershed, eastern Ethiopia. *Carbon Balance and Management* 14(7): pp 45-75.

Zhu, J. K. (2016). Abiotic stress signaling and responses in plants. *Cell*, *167*(2), 313-324.

Zaninovich, S. C., & Gatti, M. G. (2020). Carbon stock densities of semi-deciduous Atlantic forest and pine plantations in Argentina. *Science of the Total Environment*, *747*, 141085.

Zomer, R., Deborah, B. and Louis, V. (2017). Global sequestration potential of increased organic carbon in cropland soil. *Scientific Reports*, 7, 155-164.